MEMS Deformable Mirrors Advancements for Space Telescopes

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Mirror Technology Days 2012
August 1, 2012
Rochester, NY

NASA SBIR PHASE I/II
Approved for Public Release by NASA per NPR 2200

Outline

- MEMS DM technology drivers and architecture overview
- Examples of MEMS DM in astronomical applications
- Current MEMS development programs
- Next steps
- Conclusions

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Why MEMS for DMs?

Design

Easier to scale to larger arrays (**~4000**) needed for large telescope AO

Smaller size/weight/power needed for space-based AO

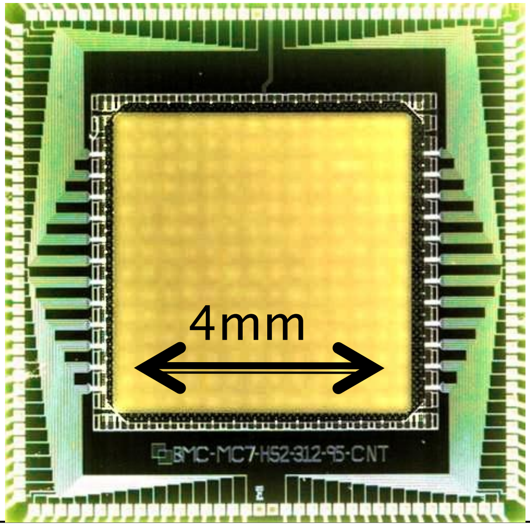
Manufacturability

10x Lower cost (**~$150/actuator**) than macroscale devices

Batch produced (vs. manual assembly)

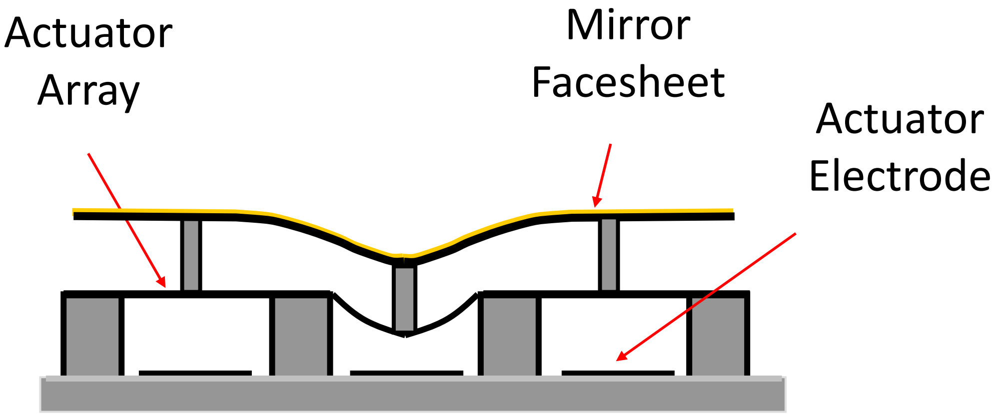
Performance

- No hysteresis
- Reliable
- Fast temporal response
- Predictable
- Compact
- Low Power
- Polarization and wavelength insensitive

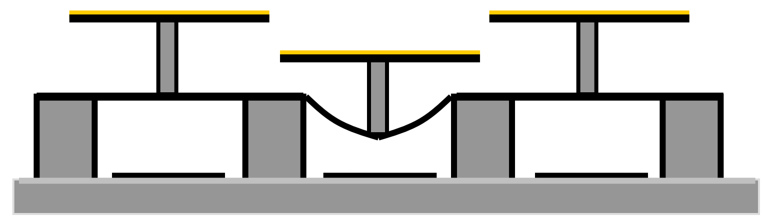


The advantages of these MEMS DMs have inspired a new generation of imaging instruments, and laser beam control systems

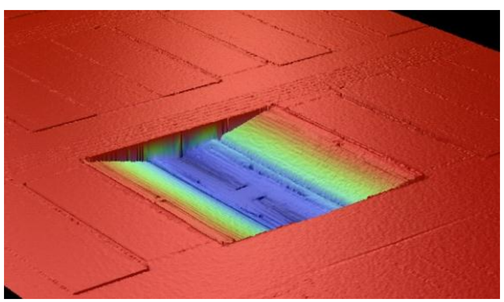
Silicon Surface Micromachined MEMS DMs



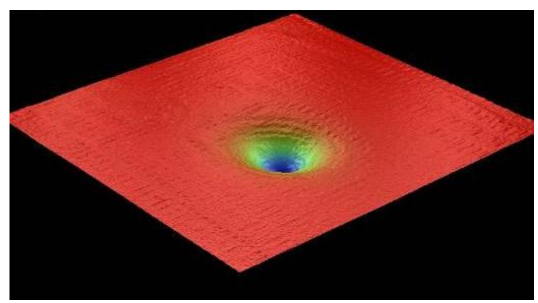
Continuous mirror (smooth phase control)



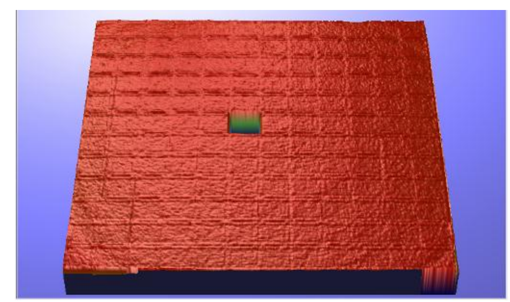
Segmented mirror (uncoupled control)



Deflected Actuator



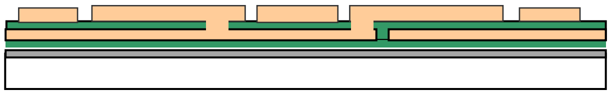
Deformed Mirror Membrane



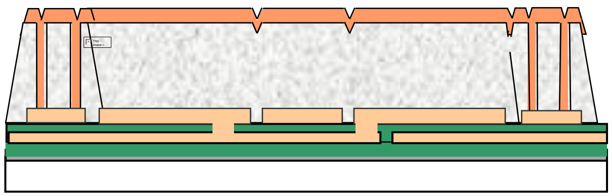
Deformed Segmented Mirror

MEMS DM Fabrication

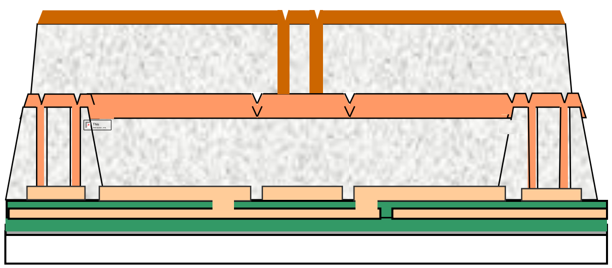
(deposit, pattern, etch, repeat)



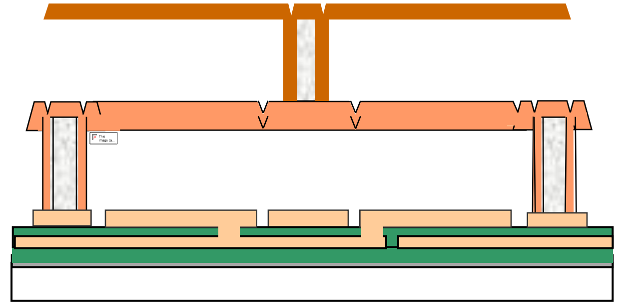
Electrodes & wire traces:
polysilicon (conductor) & silicon nitride (insulator)



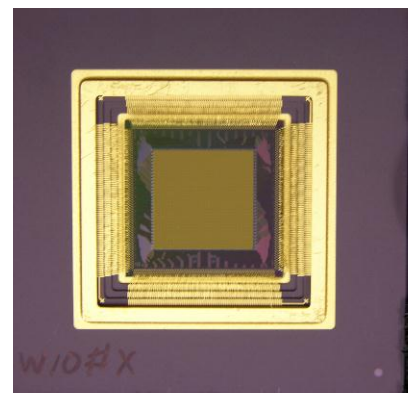
Actuator array:
oxide (sacrificial spacer) and polysilicon (actuator structure)



Mirror membrane:
oxide (spacer) and polysilicon (mirror)



MEMS DM:
Etch away sacrificial oxides in HF, and deposit reflective coating



Electrical Interconnects:
Die attach and wirebond to ceramic chip carrier

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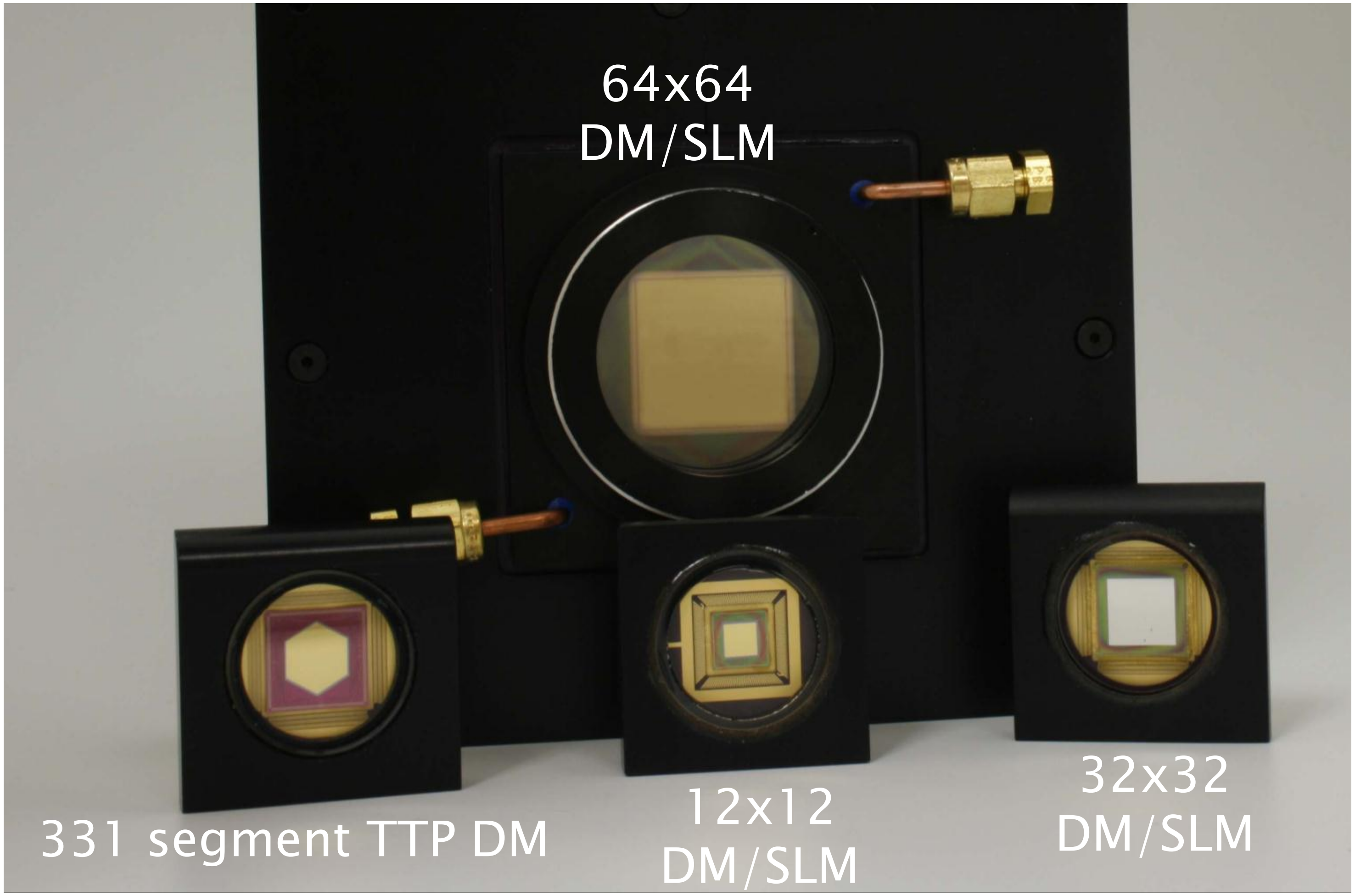
BMC Deformable Mirrors



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Observatories using BMC DMs

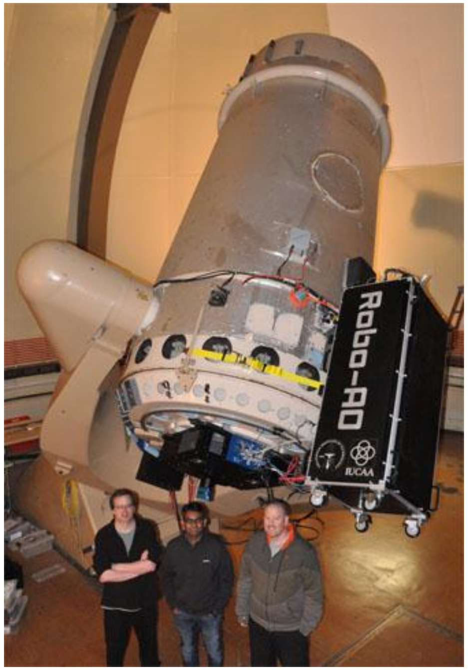
- Lick Observatory (VILLAGES):
  - 140DM used for visible AO on 1m telescope (2007)
  - Visible AO using Kilo DM on 3m telescope (on-sky 2013)

- Gemini (GPI): High contrast AO system using a 4k DM (on sky 2013)

- Subaru Telescope (SCExAO): Subaru Coronagraphic Imager with Extreme Adaptive Optics using Kilo DM (2011)

- Palomar Observatory (Robo-AO): Low-cost, autonomous, integrated laser adaptive optics system using 140 element DM (2011)

DMs in many other test beds around the world



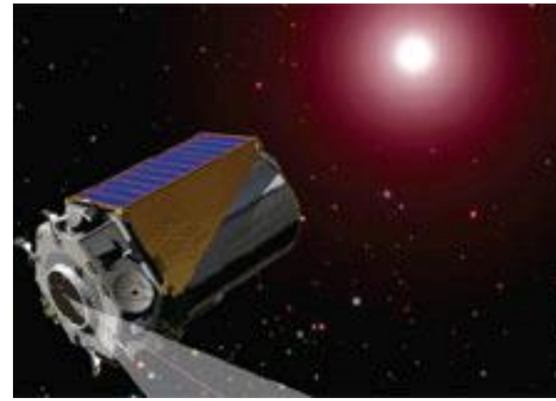
http://www.astro.caltech.edu/Robo-AO/

Robo-AO

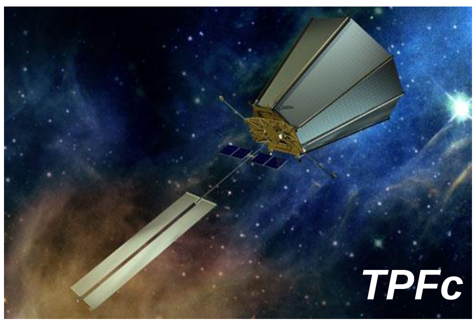

Robo-AO
Observation of Saturn in the i-band (λ = 700 - 810 nm)
from the Palomar Observatory 60" telescope
using the Robo-AO laser adaptive optics system
May 10th, 2012 6:41 UTC

MEMS DMs in Space Telescopes

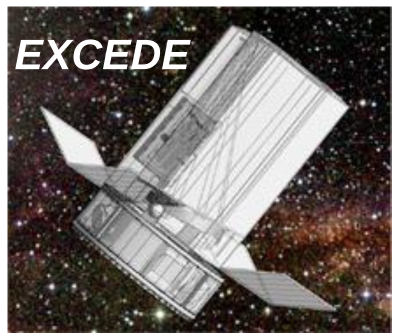
- Correction of static and slow moving (thermal) aberrations in space-based optical imaging systems
  - Astronomy – Direct Planet Detection
    - High Contrast Imaging
  - Reconnaissance
    - Correction of surface figure errors in Light weight primary mirrors



Extrasolar Planetary Imaging Coronagraph

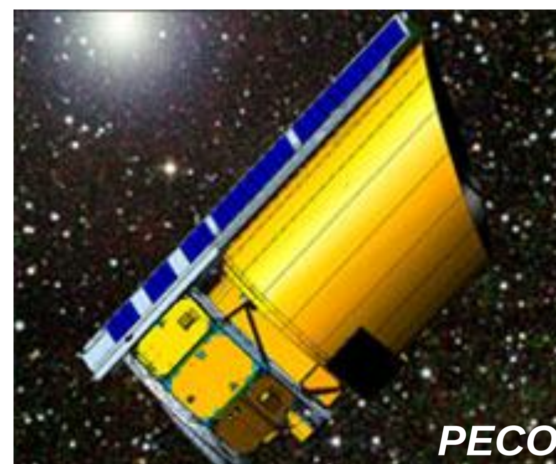


Terrestrial Planet Finder Coronagraph



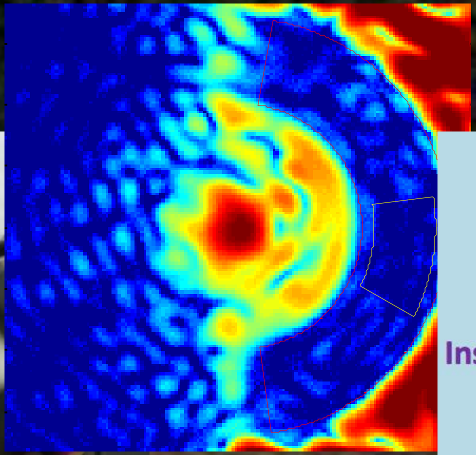
The Exoplanetary Circumstellar Environment and Disk Explorer

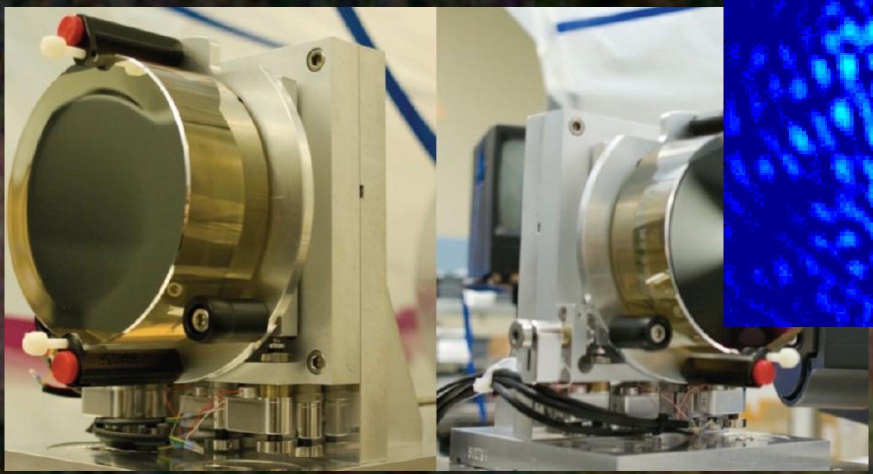
Space Infrared Telescope for Cosmology and Astrophysics

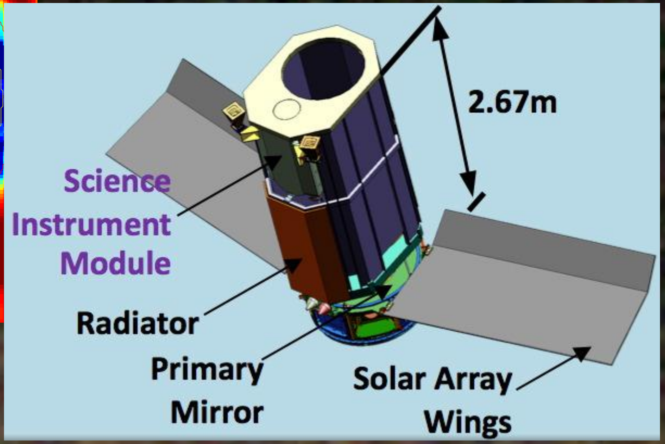


Pupil-mapping Exoplanet Coronagraphic Observer

Development of the Phase Induced Amplitude Apodization Coronagraph for an Explorer Mission







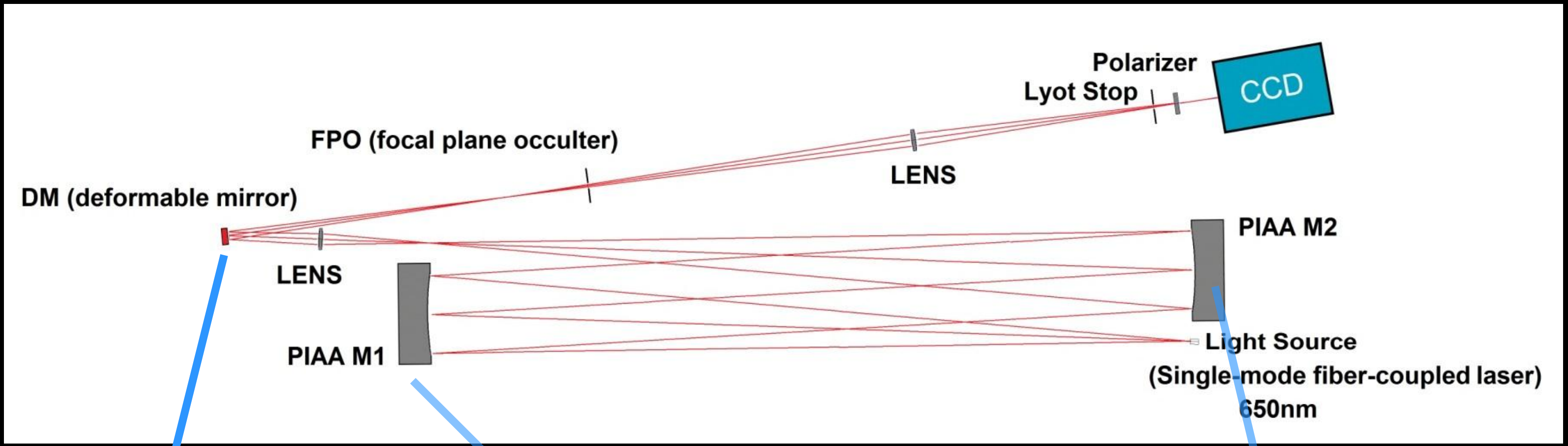
Ruslan Belikov, Eugene Pluzhnik, Fred C. Witteborn, Dana H. Lynch, Thomas P. Greene, Peter T. Zell
(NASA Ames Research Center)

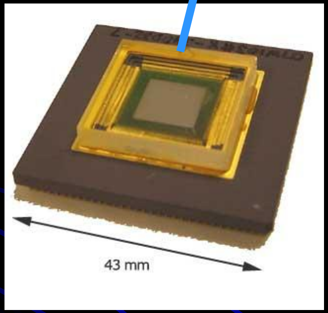
Glenn Schneider, Olivier Guyon
(University of Arizona)

Domenick Tenerelli, Alan Duncan, Rick Kendrick
(Lockheed Martin Space Systems Company)

BAASM, July 29, 2012

Experiment

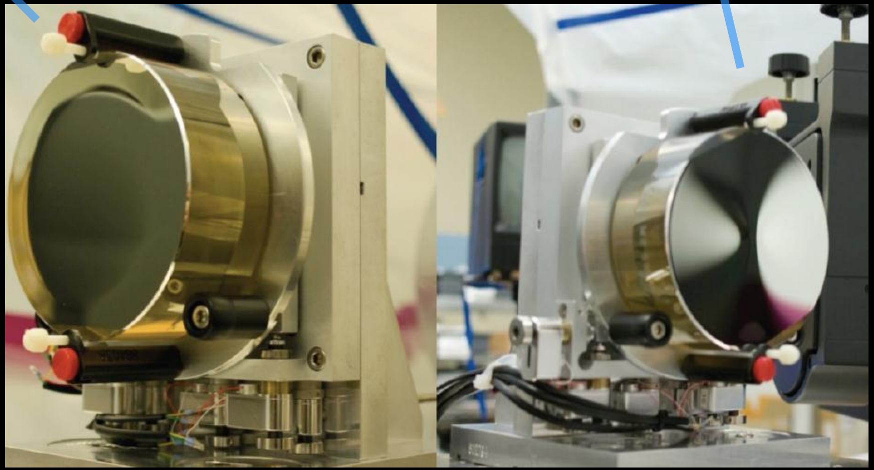




PIAA Coronagraph

Boston Micromachines Deformable mirror (32x32)

Wavefront control uses a combination of EFC) and Speckle Nulling



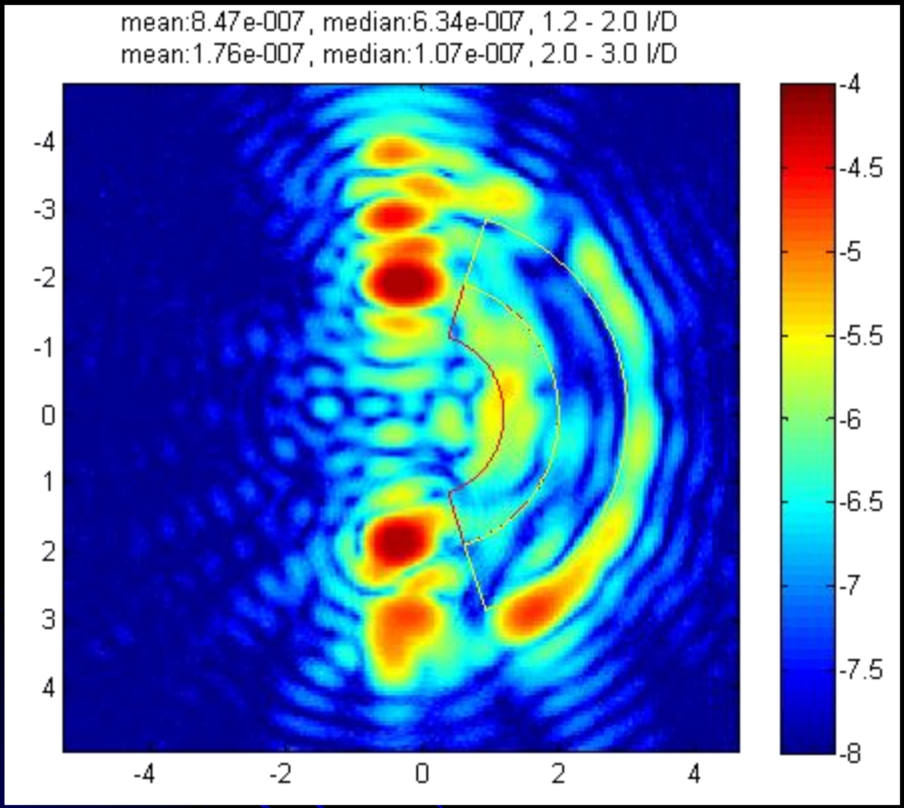
Broadband-capable PIAA mirrors made by L-3 Tinsley

Ruslan Belikov, NASA Ames Coronagraph Laboratory

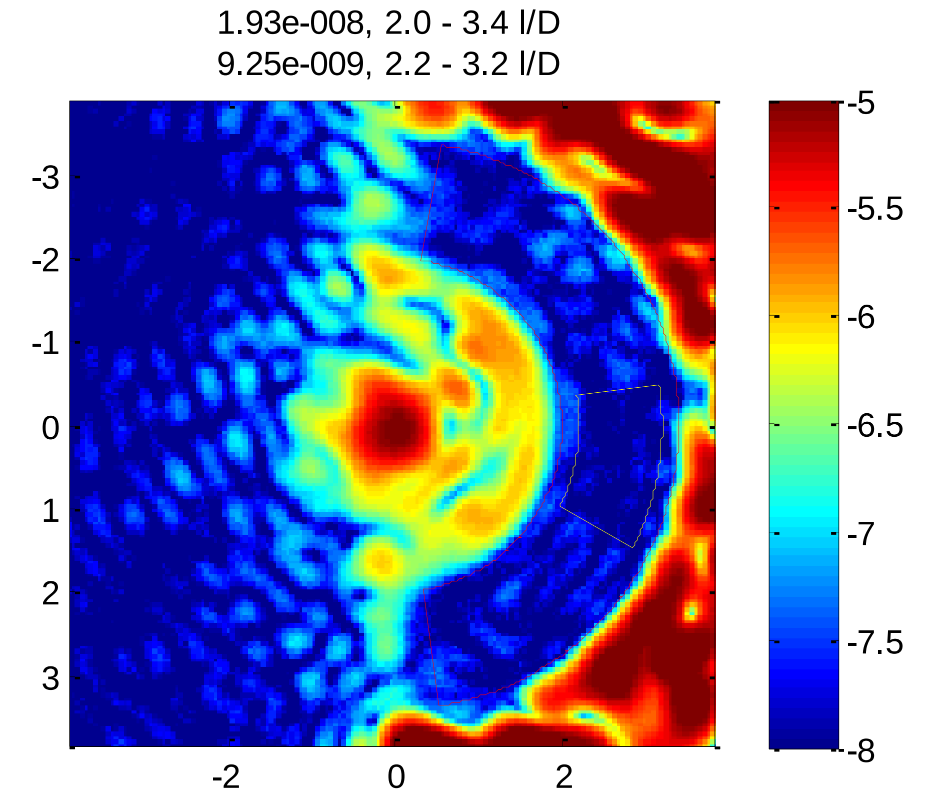
Results

(655nm light)

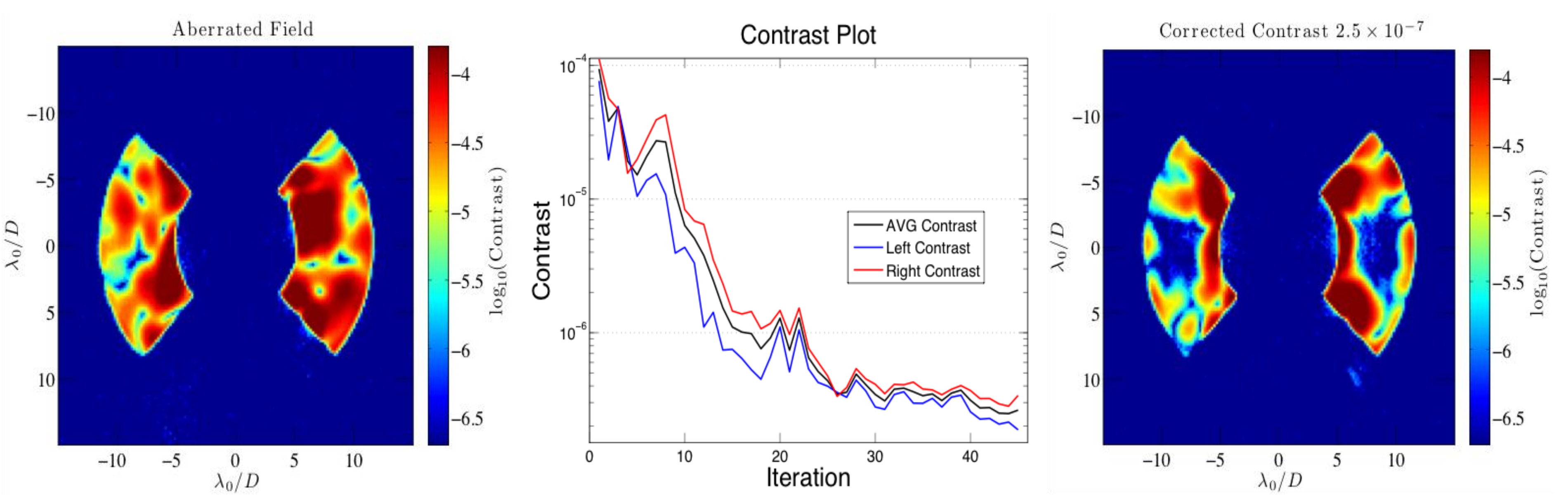
8e-7, 1.2-2.0 λ/D



1.9e-8, 2.0-3.4 λ/D



Kalman Filter Single Measurement Update



2.5 x 10^{-7} in 43 iterations
Fewest required measurements to date in Princeton's HCIL

- Only one measurement update required per iteration
- Noisy start highlights the sensitivity of estimate to probe quality

Jeremy Kasdin and Tyler Groff, Princeton University

Good, but not good enough

NASA Wants

- More actuators for better wavefront control
- Proven reliability and protection against single point failures
- Better surface finish
- Reduction in size, weight, and power

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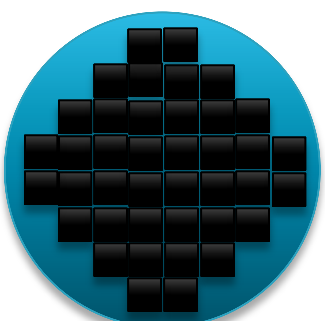
Enhanced Fabrication Processes Development for High Actuator Count Deformable Mirrors

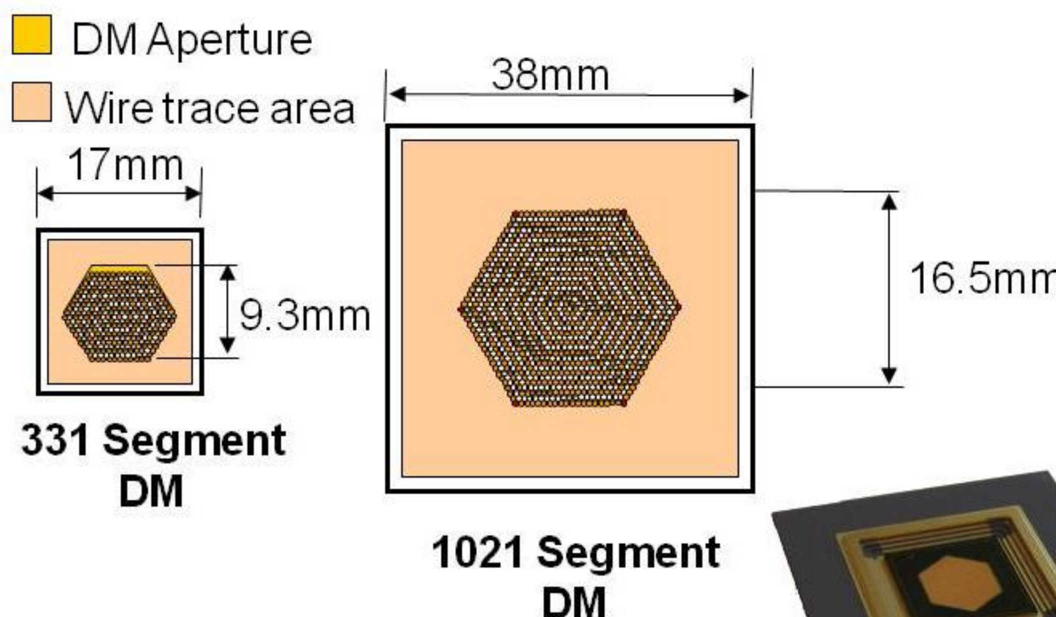
SBIR Phase II

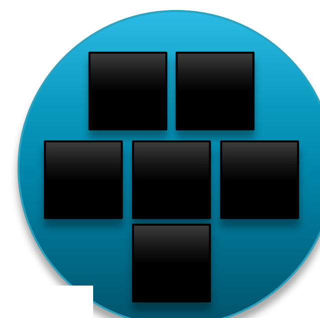
Contract # NNX11CB23C

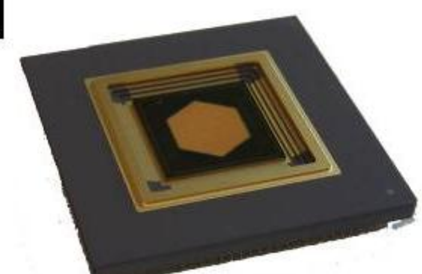
1021 Element Tip-Tilt-Piston MEMS DM

- Scale up mirror segments/actuators from 331/993 to 1021/3063
- Device architecture and fabrication process fundamentally scalable
- Challenge:
  - Managing inherent microscopic manufacturing defects (function of die area)
  - Controlling surface figure errors resulting from substrate bow and polishing









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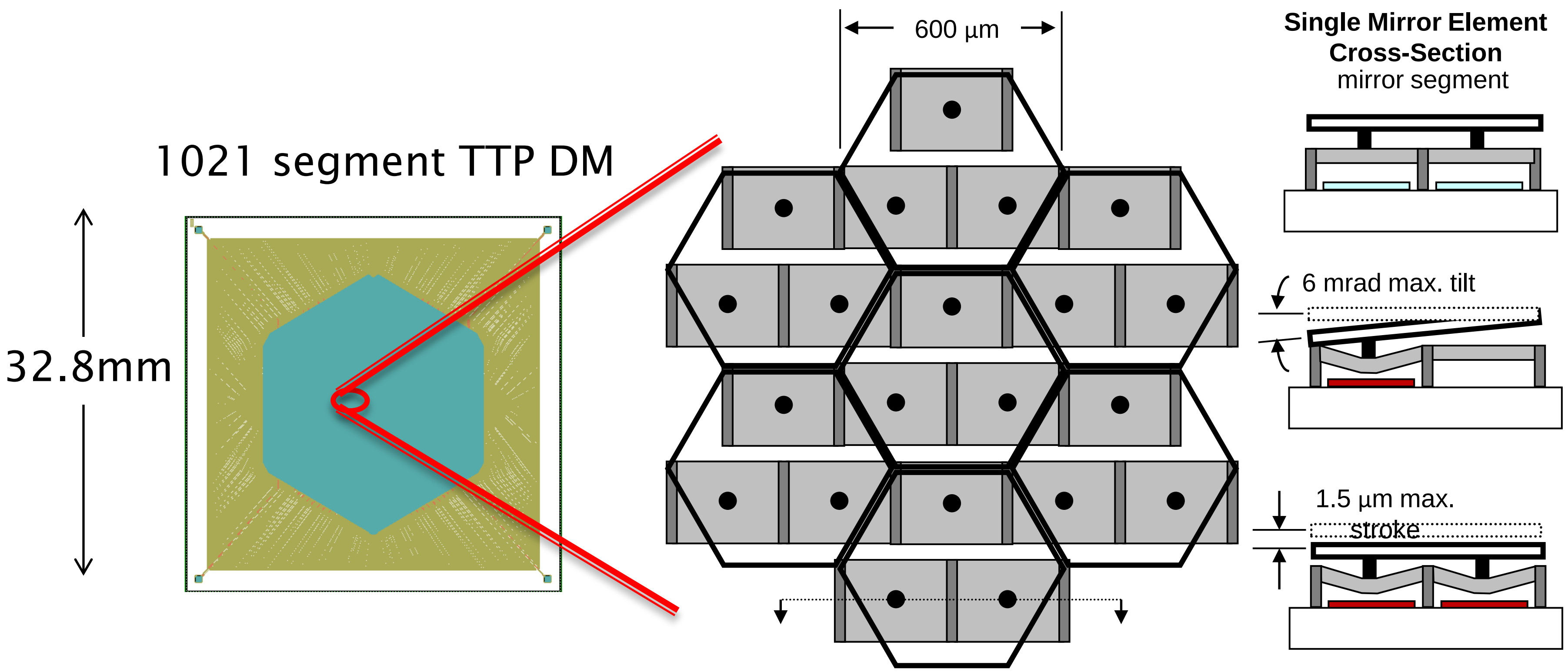
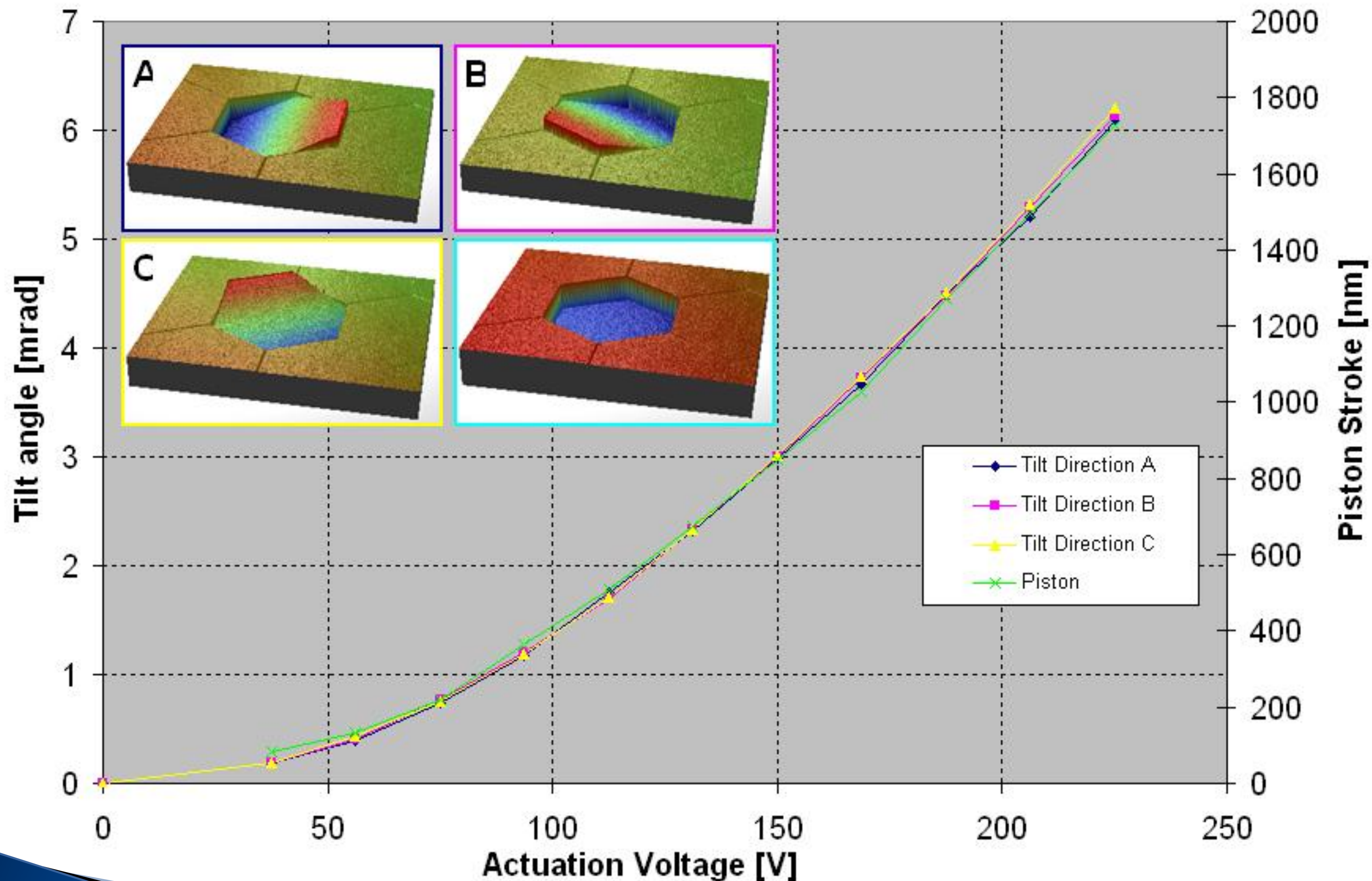
3063 Actuator DMs

- Under development for astronomical instrumentation



Electromechanical Performance - Tip/Piston



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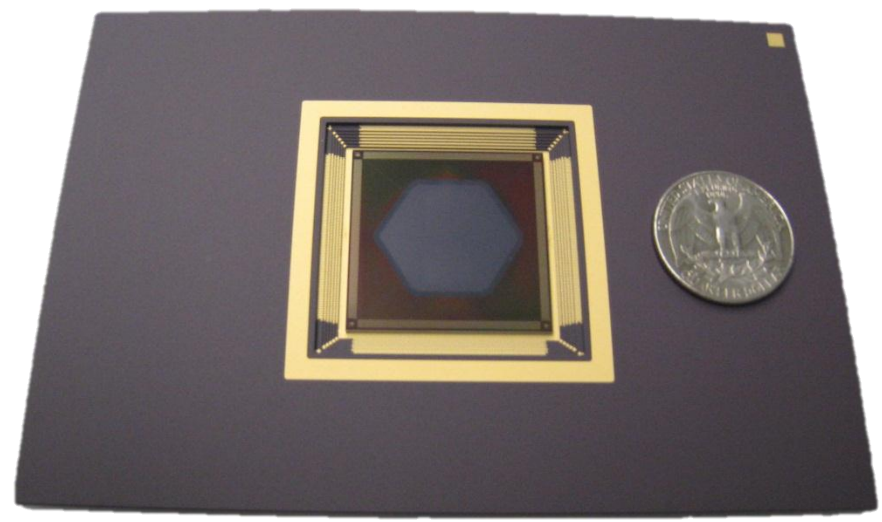
Tip/Tilt/Piston DM Development Status

- "Send ahead" wafer in house
- Will check actuation and yield
- Final fabrication by end of Q3



Enhanced Reliability MEMS Deformable Mirrors for Space Imaging Applications

SBIR Phase II

Contract # NNX12CA50C

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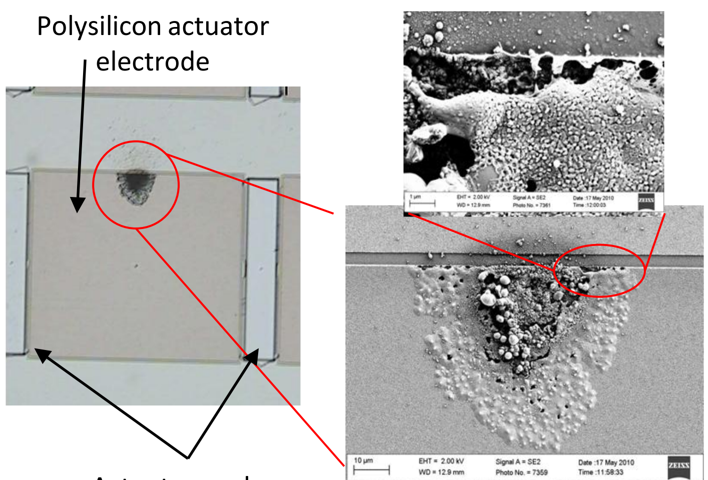
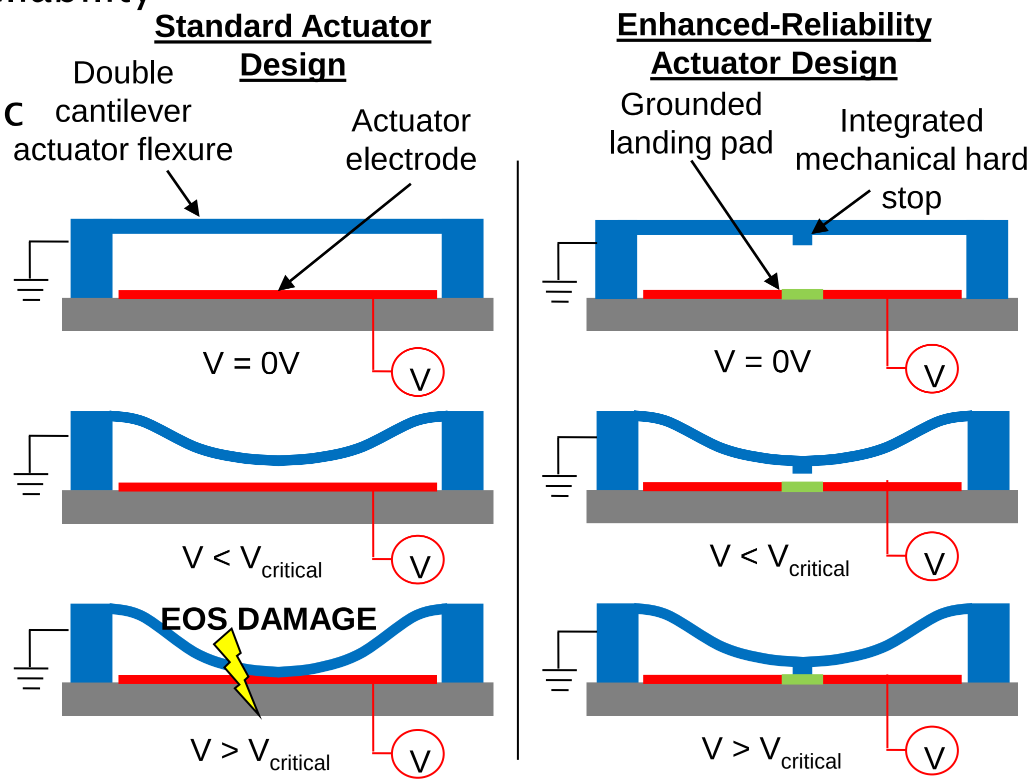
Enhanced Reliability DM Actuators

- Although MEMS DMs have been demonstrated to be reliable under normal operating conditions the electrostatic actuators, space systems require redundant measures to ensure high reliability

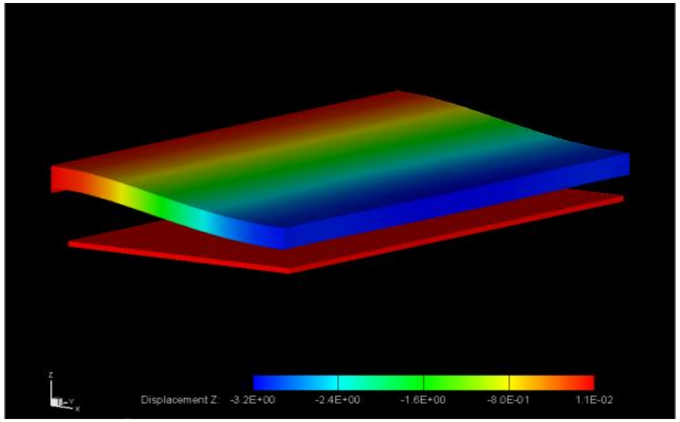
- MEMS DM system tolerant of electronic over-stress (EOS) demonstrated
  - Prevent irreversible failures due to actuator snap-through



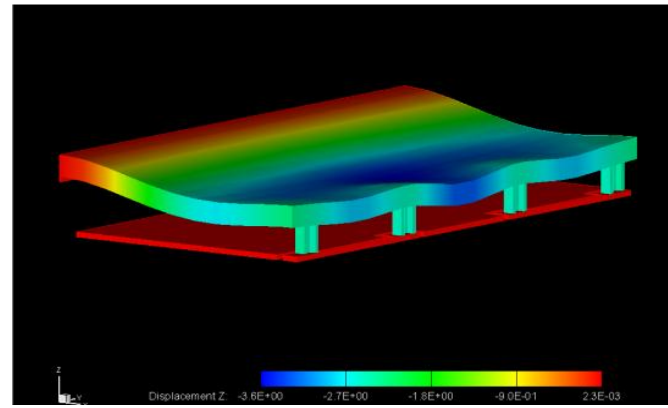


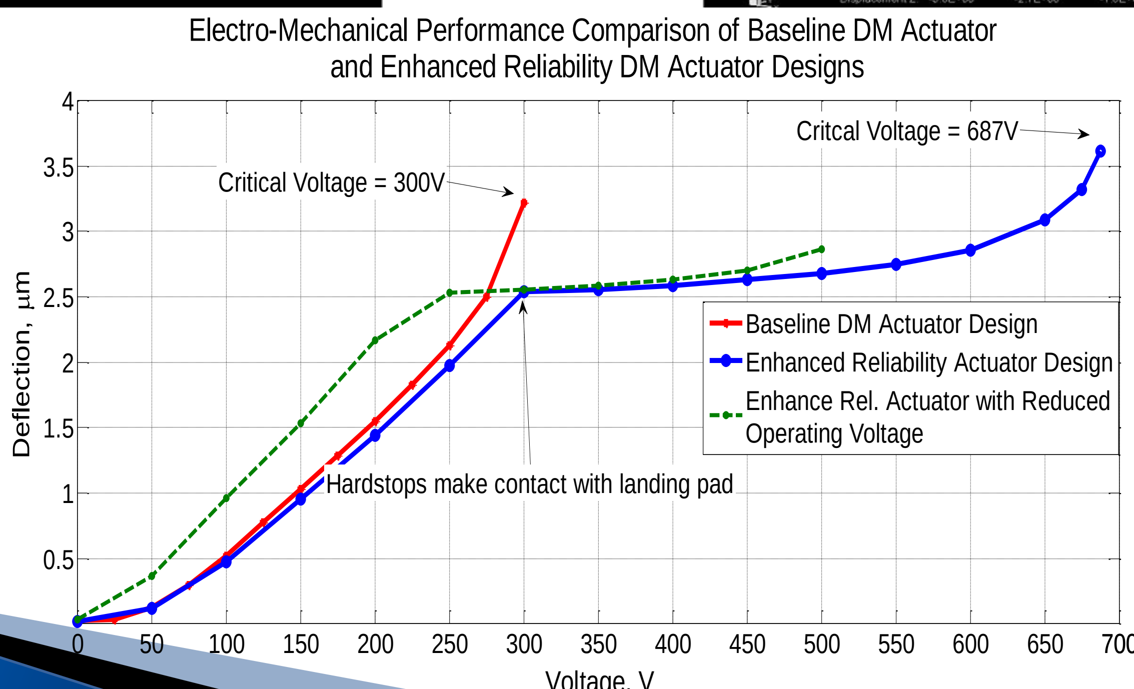
New Actuator Electromechanical Performance

Baseline Actuator Design



Enhanced Reliability Actuator Design





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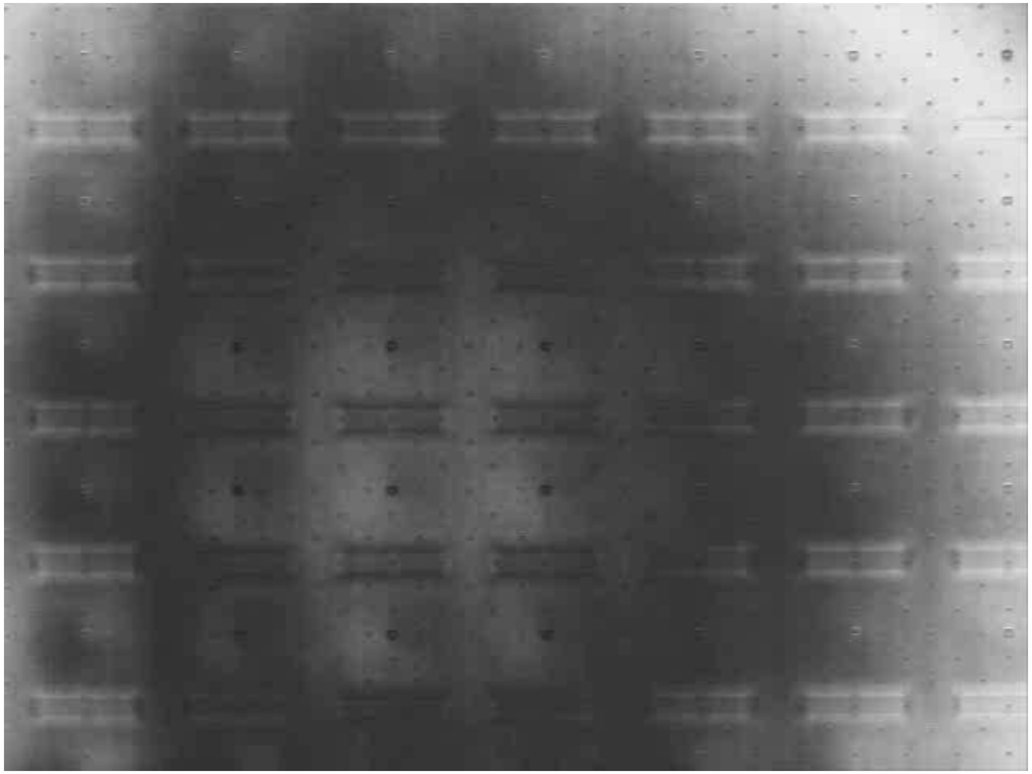
Prevention of Snap-Through Related Damage

- Addition of current limiting elements further increases overall MEMS DM reliability
  - Eliminates high-current densities at snap-through



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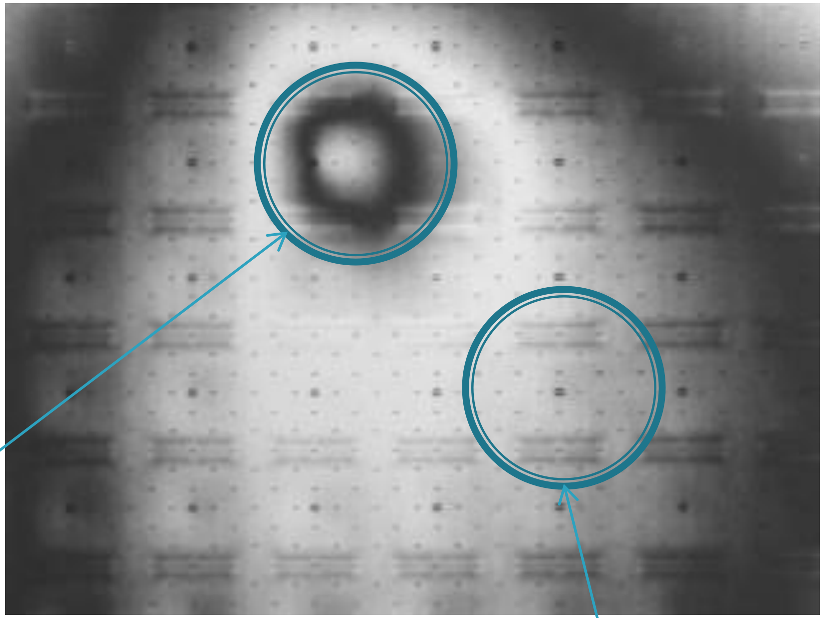
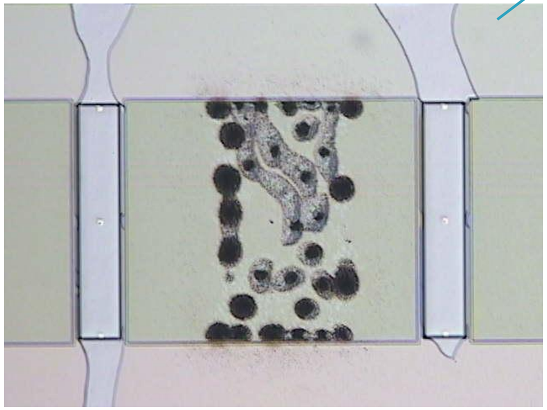
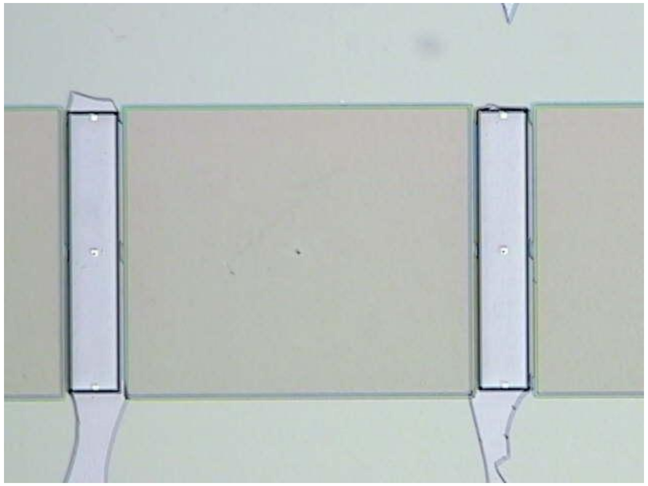


Without Current Limiting electronics

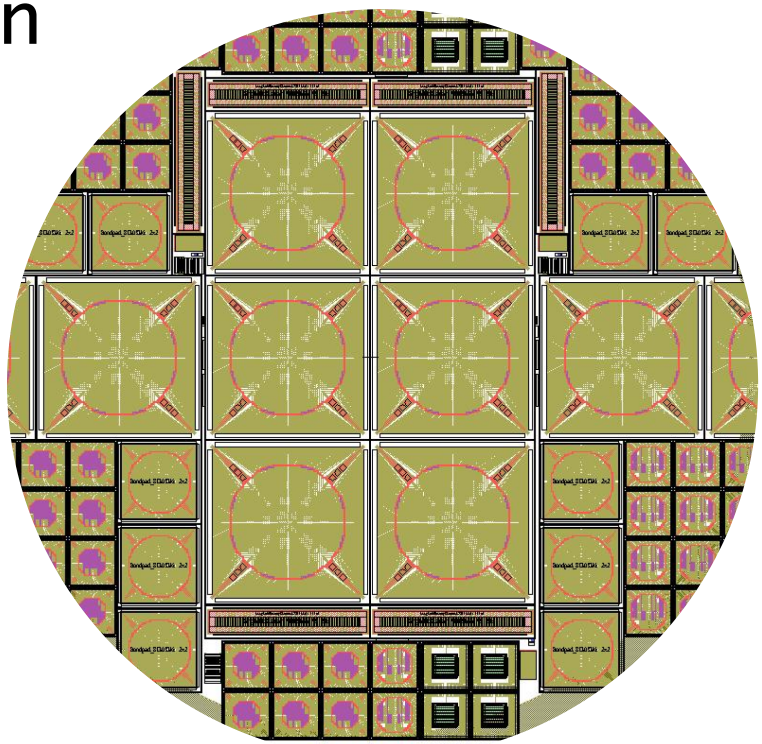


With Current Limiting electronics



New Layout Completed

- Incorporates new enhanced reliability design
- Includes 2048 actuator mirrors
- 48 actuators across aperture
- 300um and 400um pitch
- Fabrication to begin in ~1 month
- Completion in Q2 2013



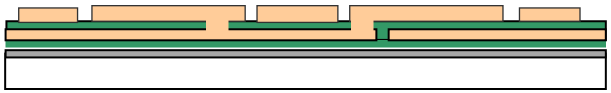
Topography improvements in MEMS DMs for high-contrast, high-resolution imaging

SBIR Phase I

Contract # NNX12CE60P

MEMS DM Fabrication

(deposit, pattern, etch, repeat)



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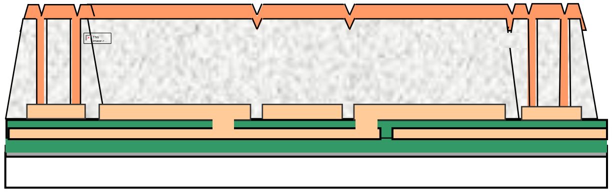

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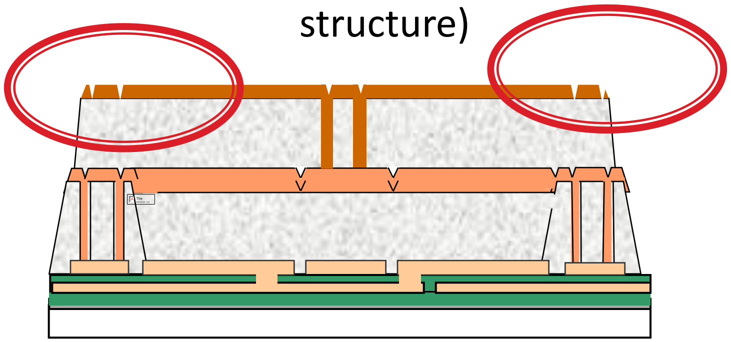
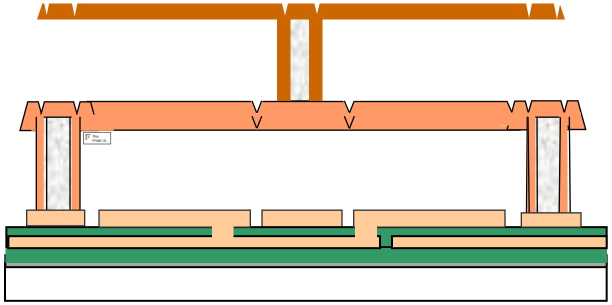
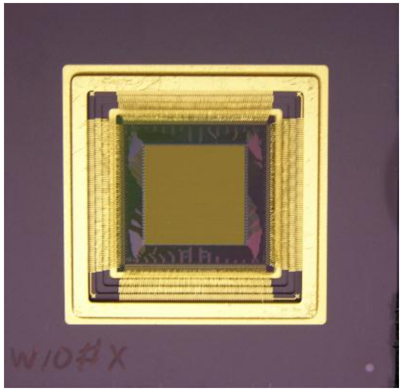


Mirror membrane:
oxide (spacer) and polysilicon (mirror)



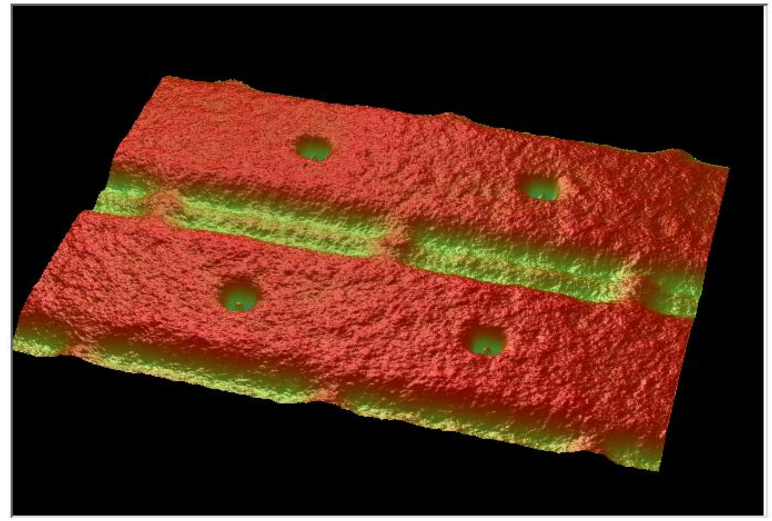
MEMS DM:
Etch away sacrificial oxides in HF, and deposit reflective coating

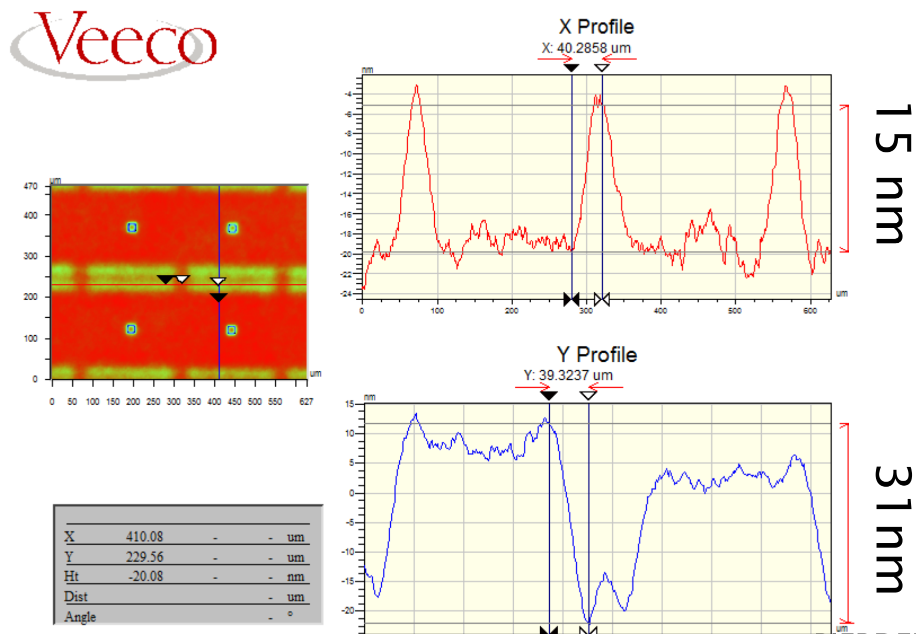


Electrical Interconnects:
Die attach and wirebond to ceramic chip carrier

Surface finish of standard polished device

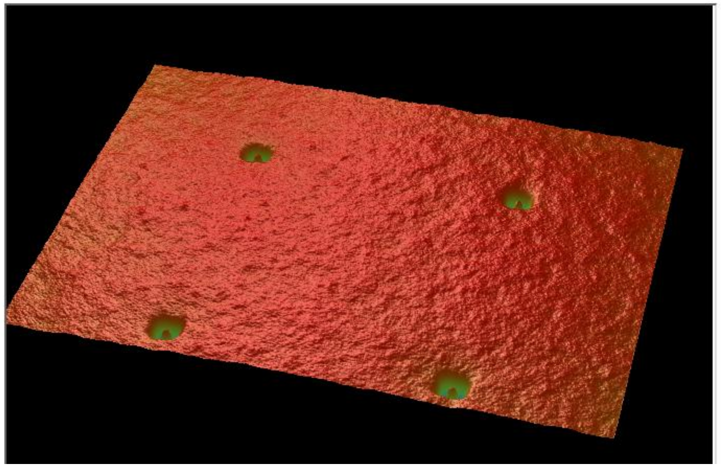
- Rq = 9.6nm RMS
- Surface finish from print through areas
- Small areas outside print through = 1.2nm RMS (100um x 100um area)

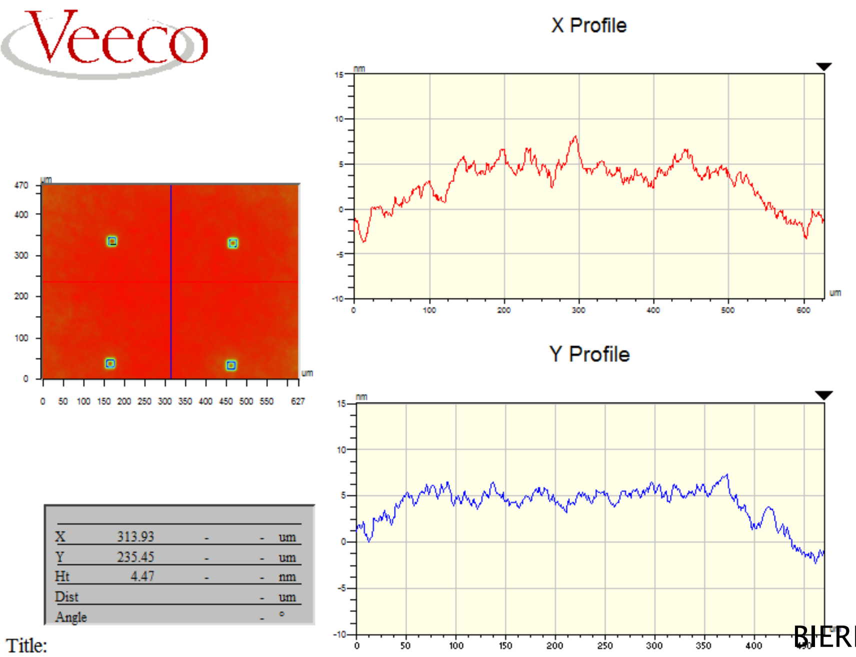




Surface finish of modified process

- Rq = 2.2nm RMS
- Combination of fabrication process, new polishing approach, and anneal modifications resulted in elimination of print through





Compact Low-Power Driver for Deformable Mirror Systems

SBIR Phase II
Contract #NNX11CB22C

Multiplexed DM Drive Electronics

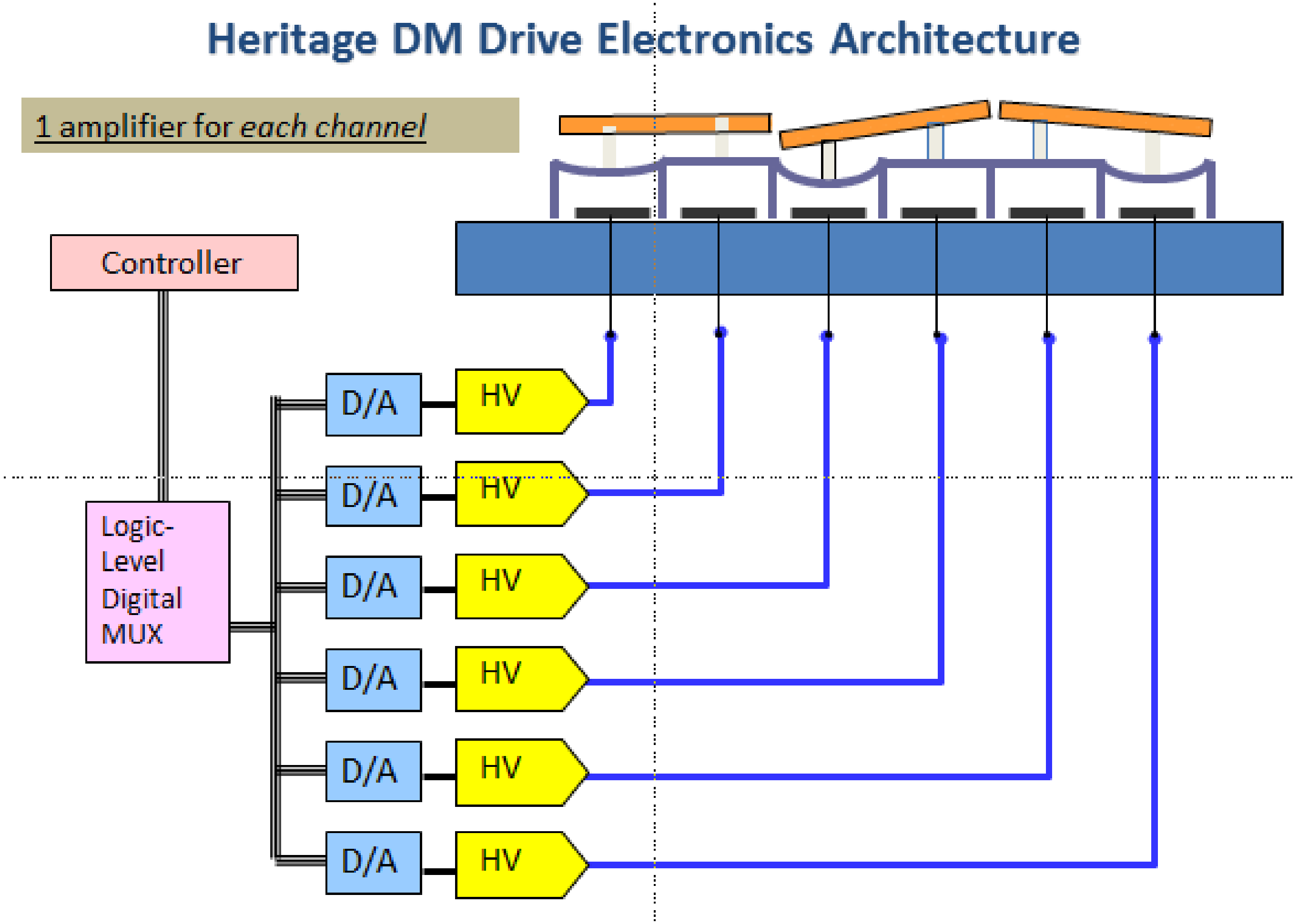
- Existing DM drive electronics using single DAC and amplifiers for each DM drive channel
- MEMS DM actuator is a capacitor – most power consumed driving high voltage amplifiers & DACs
- Space-based platforms require low power, more compact , and light weight electronics

Existing MEMS DM Driver Specification

- # Channels: 4,096 channels
- Power Consumption: 80W (typ)
- Resolution: 14 & 16-bit
- Mass (w/ cables): 13.6kg
- Max Frame Rate: 24kHz
- Size: 3U Chassis (5.25” x19” x14”)

- We are developing DM drive electronics with a 100x reduction in power consumption and 16-bit (40pm) precision

Reduction in SWAP of driver
(Size Weight and Power)



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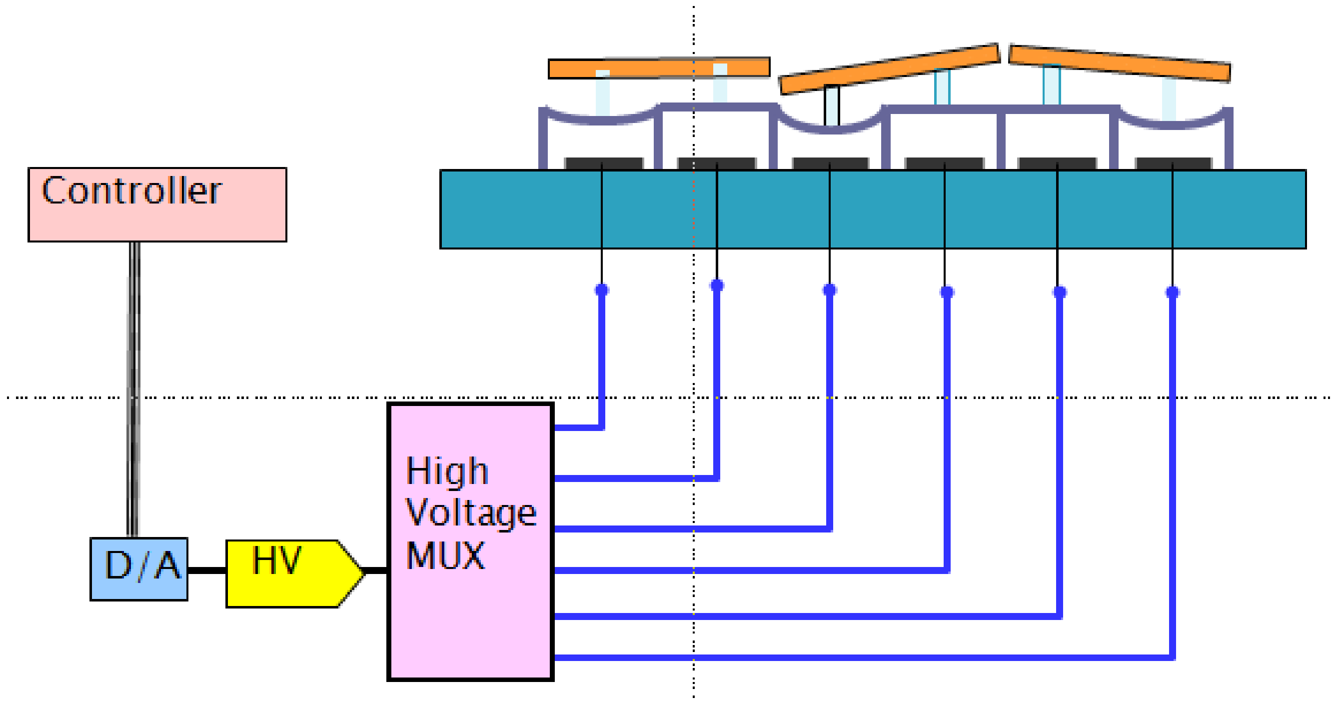
Multiplexed DM Drive Electronics Architecture



1 amplifier for *entire system*

5mW per Channel

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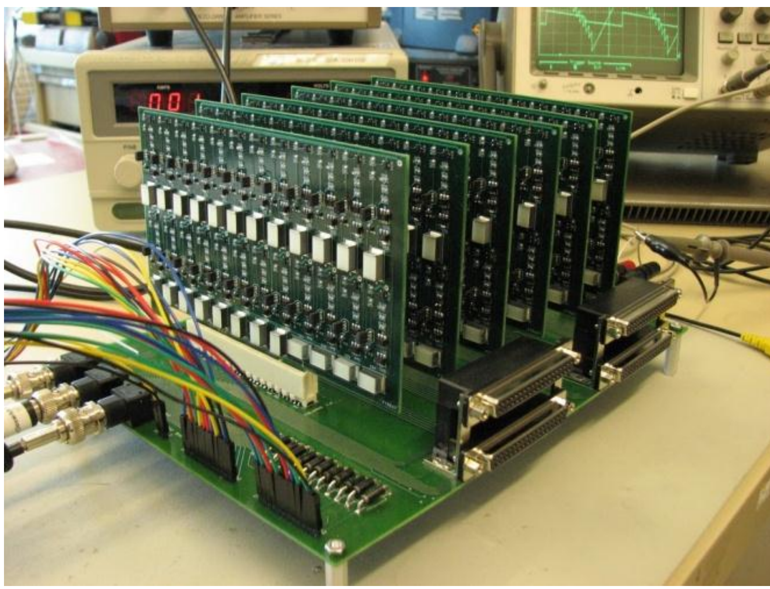
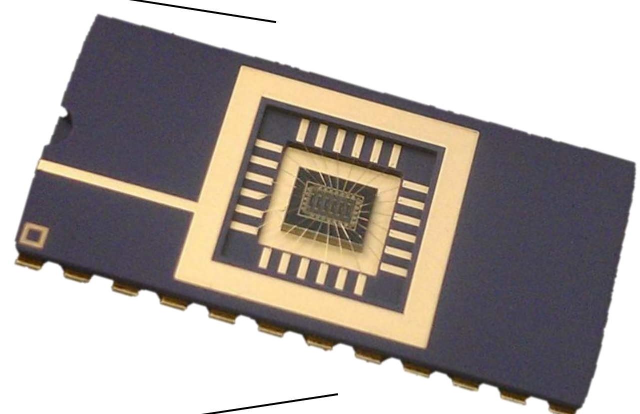
Multiplexed Drive Electronics

- Prototype multiplexed drive electronics developed
  - 16-bit resolution/<10pm step size
- Integrated into HV ASICs for ultra compact form factor
  - DALSA CMOSP8G/HighVoltage Process
- First Protoype Chips (small channel count) in and testing





Outline

- MEMS DM technology drivers and architecture overview
- Examples of MEMS DM in astronomical applications
- Current MEMS development programs
- Next steps
- Conclusions

MEMS Deformable Mirror Technology Development for Space-Based Exoplanet Detection

TDEM

Contract # Imminent

Selected for contract, but not signed

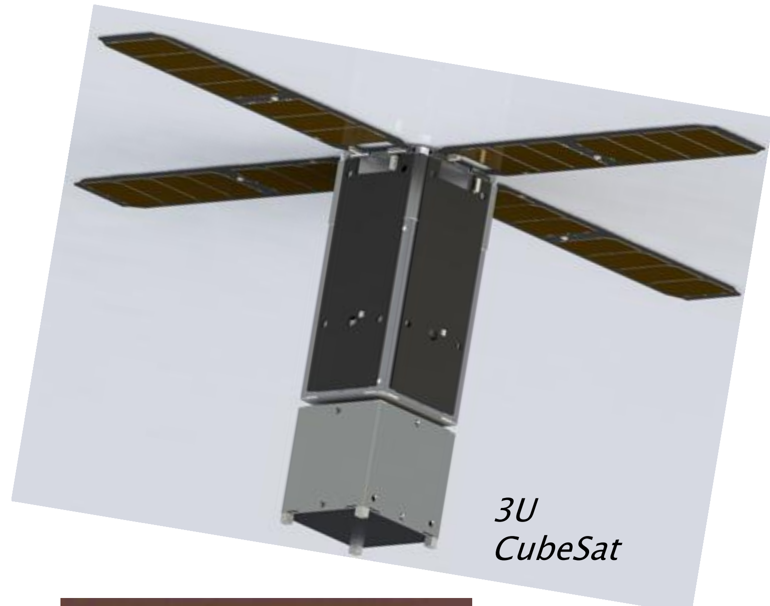
TDEM Program

- Fabricate and characterize 1k actuator continuous-surface and tip-tilt-piston devices (18 devices)
- Distribute to test beds for characterization
  - Goddard: Visible Nulling Coronograph
  - Princeton: High Contrast Imaging Laboratory
  - JPL : ExEP laboratory
- Environmental testing at Goddard Environmental Test & Integration Facilities
  - Shock/Vibe
  - Acoustic
  - Thermal-Vac
- Re-characterize at test beds

CubeSat MEMS Deformable Mirror Demonstration

Characterization of a Wavefront Control system on-orbit

Long duration operation in space environment, software and microcontroller, operations, data management



3U CubeSat

- Dr. Keri Cahoy, MIT
- Boeing Assistant Professor Department of Aeronautics and Astronautics

BMC Mini MEMS DM

Outline

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Conclusion

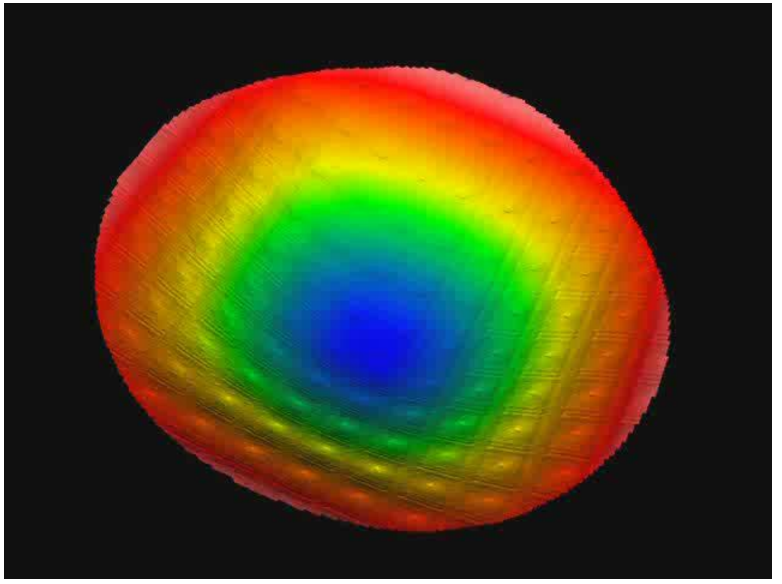
Boston Micromachines Corporation is advancing MEMS deformable mirror technology to meet needs for spaced based Adaptive Optics systems through NASA's SBIR program

Acknowledgements

- Funding from NASA/JPL
  - SBIR Phase I/II # NNX10CE09P/NNX11CB
  - SBIR Phase I /II# NNX10CE08P/NNX11CB
  - SBIR Phase I/II # NNX11CF40P/ NNX12C
  - SBIR Phase I NNX12CE60P
- M. Horenstein at Boston University Photonics Center

Thank You

Questions?



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